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Assessment of phosphorus fixing capacity in contrasting soil orders in central India

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Abstract

Phosphate adsorption by soils is important because adsorbed P equilibrates with soil solution P, which in turn is immediate source of P. While P fixation continues to receive much attention it is more important to know the effect of soil characteristics on P fixation. Phosphorus sorption characteristics of JNKVV, Farm, Jabalpur representative agricultural soils belonging to three soil orders namely Vertisol, Inceptisol and Alfisol were investigated for adsorption behaviour of P and sorption data were fitted to Langmuir equation. The Langmuir constant i.e. adsorption maxima was highest for Vertisol (504.26 $\mu\text{g g}^{-1}$), followed by Alfisol (480.89 $\mu\text{g g}^{-1}$) and Inceptisol (452.98 $\mu\text{g g}^{-1}$) respectively. The phosphate adsorption isotherm gave good fit adopting Langmuir ($r^2 = 0.98$ to 0.99) for the three soils. The value of equilibrium solution P concentrations were found significantly variation under different soil orders but the adsorb P value was also found significant varied. The equilibrium solution P concentrations minimum in Alfisols 0.03 to 8.95 $\text{mg}\mu\text{g mL}^{-1}$ and maximum in Inceptisols 0.09 to 10.95 $\mu\text{g mL}^{-1}$, but the adsorb P value was minimum in Inceptisols 19.01 to 290.41 $\mu\text{g mL}^{-1}$ and maximum were recorded in Alfisols 19.64 to 310.47 $\mu\text{g mL}^{-1}$. In Vertisols the value of equilibrium solution P concentrations were found in the range of 0.13 to 10.08 $\mu\text{g mL}^{-1}$ and adsorb P values were 18.65 to 299.13 $\mu\text{g mL}^{-1}$. The range of P buffering capacity was 60.07 to 70.89 L kg^{-1} . The highest value of MPBC was found in Alfisols with the mean value 68.89 L kg^{-1} and the lowest of MPBC value was found in the Inceptisols with the mean value was 63.72 L kg^{-1} . Correlation of Adsorption parameters of Langmuir and were worked out taking all soil types together with pH, EC, organic carbon, clay, CEC and CaCO_3 . For the Langmuir equation, value of 'r' indicated that P adsorption maxima (b) was significantly and positively correlated with pH ($r=0.993^{**}$), clay (0.916^{**}) EC ($r=0.734^*$).

Keywords: Phosphorus, sorption maxima, vertisol, inceptisol, alfisol, standard P requirement

Highlights

- Soils were found neutral to slightly alkaline in soil reaction, safe in electrical conductivity, low to medium in organic carbon content and non- calcareous nature.
- The adsorption in three major soil orders of illustrated that the Langmuir models can be used to describe satisfactorily P sorption on soil colloids. Among the three soil orders highest P sorption was observed in Vertisol followed by, Alfisol and Inceptisol.
- Correlation of P sorption maxima with clay content illustrating that soil texture played a major role in P sorption of these soils.
- The SPR values indicated high P requirement in Inceptisols as compared to Alfisols and Vertisols to maintain 0.2 mg P L^{-1} in soil solution for optimum crop growth. The high P adsorption by Vertisols showed higher phosphate buffering capacity and would maintain low P in soil solution P as compared to Alfisols and Inceptisols.

1. Introduction

Phosphorus sorption governs the supply of labile inorganic P (fertilizer P) and the isotherm helps in predicting the efficiency of crops to utilize that labile P. It is a well-known fact that phosphate adsorption depends upon many soil properties like clay content, CaCO_3 , organic matter, Al and Fe content, CEC as well as P sources applied to soil (Saha *et al.*, 1999; Majumdar *et al.*, 2005) [18, 10].

In order to understand the complex behaviour of P in soil, several workers have emphasized the importance of P fertilizer management based upon chemical extraction methods (soil-test methods) and phosphate adsorption isotherms (Hue *et al.*, 2000) [6]. But, P sorption method has

an edge over chemical extraction methods as it also defines the efficiency of the crops to utilize the P available from soil. Sorption curves also integrate quantity and intensity parameters to characterize the capacity of soil to supply P to soil solution and predicting fertilizer requirement. Adsorption equations of Langmuir have been used by many workers worldwide to measure relative phosphate sorption capacity of different soils and the affinity of adsorbate to adsorbent, to understand the sorption phenomenon.

The availability of phosphorus is controlled by the fixation mechanism. Prediction of response to P application is generally based on available P status as well as on the rate and magnitude at which the added P is converted into insoluble forms in soil (Tekchand and Tomar, 1993) [21]. Phosphate adsorption by soils is important because adsorbed P equilibrates with soil solution P, which in turn is immediate source of P. While P fixation continues to receive much attention it is more important to know the effect of soil characteristics on P fixation.

2. Material and Method

2.1 Description of study area and sites

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, is situated 23°12'57" latitude and 79°56'49" longitude and altitude of 383.3 m above mean sea level. Breeder Seed Production of Field Crops (BSP-FC) in which dominant soils were Vertisol, classified as Typic Haplusterts, Family-Very fine montmorillonite hyperthermic (Tripathi 1998) [24] and Inceptisol, Vertic Ustochrept, fine mixed hyperthermic

(Kulkarni, 1986) [8]. The soils of BSP-FC Farm are clayey in texture.

Krishi Nagar Research Farm in which soil order was Alfisol and classified as Typic and Vertic Haplustalf, Fine loamy and mixed, hyperthermic, locally knew as sehra soils. The texture was found to be sandy clay loam and sandy loam (Dhakad, 2017) [2].

Breeder Seed Production of Groundnut (BSP-Groundnut) in which soil type was Inceptisol and classified as Typic Ustochrept, Fine loamy and mixed, hyperthermic (Tripathi, 1998) [24].

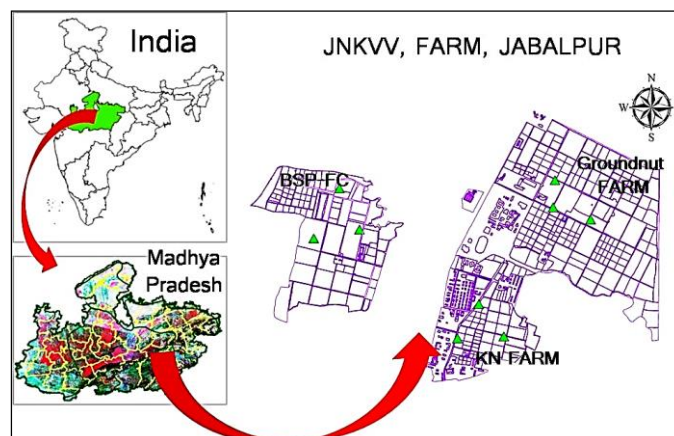


Fig 1: Location of Soil sampling

Table 2.1: Details of soil used

Farm	Soil orders	Site	Latitude	Longitude	Cropping system	Sample No.
BSP-Field Crops	Vertisols	(V1)	N-23013°02.4"	S-79056°40.7"	Soybean-Wheat	3
		(V2)	N-23012°50.1"	S-79056°47.0"	Soybean-Wheat	
		(V3)	N-23013°44.6"	S-79056°36.7"	Soybean-Wheat	
Krishi Nagar Research Farm	Alfisols	(A1)	N-23012°17.6"	S-79057°17.6"	Rice-Wheat	3
		(A2)	N-23012°18.2"	S-79057°32.1"	Rice-Wheat	
		(A3)	N-23012°27.8"	S-79057°24.3"	Rice-Wheat	
BSP-Groundnut	Inceptisols	(I1)	N-23012°53.1"	S-79057°59.2"	Rice-Wheat	3
		(I2)	N-23012°56.7"	S-79057°47.5"	Rice-Wheat	
		(I3)	N-23013°04.8"	S-79057°48.1"	Rice-Wheat	

2.2 Physico-chemical properties of soils

The soil pH was measured in a soil: water ratio of 1: 2.5 using the pH meter and supernatant of same was used for electrical conductivity determination with the help of conductivity-meter (Jackson, 1973) [7]. Organic carbon (OC) in soil was determined using method as described by (Walkley and Black 1934). The calcium carbonate in soil was carried out using rapid back titration method as described by (Jackson, 1973) [7]. The CEC of soil was analyzed by leaching it with 1N neutral NH₄OAc solution as described by (Jackson, 1973) [7]. The particle size analysis (clay percent) of soil was determined by Bouyoucos hydrometer method (Bouyoucos, 1962) [1]. Available nitrogen (N) was determined as per method given by Subbiah and Asija (1956) [20]. Available phosphorus (P) was determined by 0.5 M sodium bicarbonate by Olsen et al., (1954) [12] and then read on Spectrophotometer. Available potassium (K) was extracted with 1 N NH₄OAc and then measured by Flame Photometer (Jackson, 1973) [7].

2.3 Determination of phosphorus fixing capacity of the soils

For determination of phosphate adsorption characteristics of soil, the method suggested by Fox and Kamprath (1970) [5] was followed triplicate soil sample (3g) were equilibrated with 30ml of 0.01 M CaCl₂ solution containing graded concentrations of P (2, 4, 8, 16, 24, 32 and 40 mg P L⁻¹ Potassium dihydrogen phosphate) in 50 ml plastic centrifuge tubes for six days at 25± 1°C. Two drops of toluene were added to suspensions to inhibit microbial activity. During the equilibration period, the soil suspensions were shaken for 30 min twice daily. After six days of equilibration, the suspensions were centrifuged and filter the Whatman filter paper and P concentrations in the supernatants were determined colorimetrically (Olsen et al., (1954) [2]. The amount of P sorbed was calculated by the difference between P initially added and P remaining in solution. The phosphate adsorption data were fitted to the Classical Langmuir Isotherm equation for evaluating the goodness of fit. The different equations used are described below.

$$C = 1 + \frac{C}{Q kb b}$$

Where, C is the solution P concentration (mg P L⁻¹), q is the amount of sorbed P (mg P kg⁻¹), b is the P sorption maximum (mg P kg sorption) and k is the constant related to bonding

energy of sorption (mg kg^{-1}). The sorption maximum (b) and bonding energy (k) were computed from slope and intercept of the Langmuir P sorption isotherms, respectively. The maximum P buffering capacity (MPBC) was calculated by multiplying sorption coefficients, b and k advocated by Kuo *et al.*, (1988)^[9]. Further, standard P requirement of soil (SPR) was determined as amount of P sorbed at a solution P concentration of 0.2 mg P L^{-1} (Fox and Kamprath, 1970)^[5].

3.0 Result and discussions

3.1 Status of physico-chemical properties of soil

Data presented in table 3.1 showed that soil pH of different soil order of JNKVV farm Jabalpur, found to be 7.57, 7.59 and 7.68, 6.37, 6.95 and 7.18 and 6.72, 6.27 and 6.35 in V1, V2 and V3 (Vertisols), A1, A2 and A3 (Alfisols) and I1, I2 and I3 (Inceptisols) soil orders, respectively. Data indicates the pH of soils was found to be high in Vertisols (7.68) whereas low in Inceptisols (6.27). Raghuwanshi *et al.* (1992)^[15] analyzed Brown soils were slightly acidic (pH 5.6 to 6.6) while the black soil of Jabalpur was neutral to alkaline (pH 7.2). Similar ranges in pH values were also reported by Tripathi *et al.*, (1994)^[25]. In all the three soil orders the EC ranged from 0.07 to 0.35 dS m^{-1} at 25°C . Which was safe in limite the three soil order $< 1 \text{ dS m}^{-1}$ at 25°C . Similar results for various black soils were also reported by Tomar (1968)^[23] and Singh *et al.* (2014)^[19].

The organic carbon content in soil ranged from 4.60 to 6.60 g kg^{-1} in different orders of soil. The highest content of OC is recorded in Vertisol, which were 6.60, 5.92 and 5.87 g kg^{-1} in V2, V1 and V3, respectively. In Alfisols, the OC content found to be 5.33, 5.25, and 4.80 g kg^{-1} in A1, A3 and A2,

respectively. However, organic carbon content in Inceptisols was observed to be low in I3, I2 and I1 which having value of 5.64, 5.55 and 4.60 g kg^{-1} respectively. Organic carbon was found to be low in Inceptisols and the high in Vertisols. The OC high might be due to incorporation of organic matter on the upper layer of the soil, through roots and other plant residues and manures. The crop species and cropping systems that may also play an important role in maintaining SOC stock because both quantity and quality of their residues that are returned to the soils vary greatly affecting their turnover or residence time in soil and thus its quality.

The CaCO_3 content was found to be 40, 60, 45 g kg^{-1} and 60, 70, 40 g kg^{-1} and 65, 70, 45 g kg^{-1} in V1, V2 and V3 (Vertisols), A1, A2 and A3 (Alfisols) and I1, I2 and I3 (Inceptisols) soil orders, respectively. The data indicates that the lowest and the highest values were observed in Vertisols and Inceptisols, respectively. Concentration of CaCO_3 is high might be due to least leaching process. It is concluded that the soils are non-calcareous in nature. Similar results were reported by Singh *et al.* (2014)^[19]. The highest CEC content was found to be 58.24, 62.78, $55.23 \text{ cmol (p+) kg}^{-1}$ in V1, V2 and V3 (Vertisols) followed by 44.95, 48.21, $47.53 \text{ cmol (p+) kg}^{-1}$ and 45.75, 48.94, $46.72 \text{ cmol (p+) kg}^{-1}$ in, A1, A2 and A3 (Alfisols) and I1, I2 and I3 (Inceptisols) soil orders. The minimum CEC was existed in Alfisols and Inceptisols. However it was maximum in Vertisols, Existence of higher CEC in soils of Vertisols might be due to presence of higher clay content. Pathak (1983)^[13] reported that CEC of clay soils derived from basaltic rocks increased with clay content. Similar results were also reported by Matike *et al.*, (2011)^[11] and Singh (2014)^[19].

Table 3.1: Physico-chemical properties of different soils of JNKVV Farm, Jabalpur

Site	pH	EC (dS m^{-1})	OC (g kg^{-1})	CaCO_3 (g kg^{-1})	CEC [cmol(p+) kg^{-1}]	Clay (%)	Available major nutrient (kg ha^{-1})		
							N	P	K
(V1)	7.57	0.35	5.92	40.00	58.24	50	267.79	16.24	328.68
(V2)	7.59	0.26	6.60	60.00	62.78	55	302.70	11.09	308.32
(V3)	7.68	0.22	5.87	45.00	55.23	52	250.88	15.15	345.60
(A1)	6.37	0.16	5.33	60.00	44.95	25	279.97	30.53	298.08
(A2)	6.95	0.12	4.80	70.00	48.21	20	245.06	30.79	276.96
(A3)	7.18	0.15	5.25	40.00	47.53	22	276.97	24.91	322.80
(I1)	6.72	0.08	4.60	65.00	45.75	25	239.14	21.34	336.08
(I2)	6.27	0.09	5.55	70.00	48.94	30	251.06	17.60	323.36
(I3)	6.35	0.07	5.64	45.00	46.72	32	272.23	22.00	289.76

3.2 Status available major nutrients in soils

3.2.1 Available N

The data pertaining to available major nutrients, presented in table 3.1 indicated that the low available N content was recorded in Inceptisols soil order, which showing value of 272.23, 251.06 and $239.14 \text{ kg ha}^{-1}$ in I3, I2 and I1, respectively. In Alfisols, the available N was recorded to be 279.97, 276.83 and $245.06 \text{ kg ha}^{-1}$ in A1, A3 and A2, respectively. However, the available N content in soils was observed to be high in Vertisols, which having value of 302.70, 267.79 and $250.88 \text{ kg ha}^{-1}$ in V2, V1 and V3, respectively. The low nitrogen content in the soils is attributed due to high temperature, removal of organic matter leading to nitrogen deficiency. The medium nitrogen status in some area may be due to application of N fertilizer recommended for the crops. Soils with higher levels might be the contribution from the leguminous cover crops for the crops and very little tillage. Similar results were reported by Dubliya, 2011 and Singh *et al.*, (2014)^[19]; Ravikumar and Somashekar (2014)^[7].

3.2.2 Available P

The available phosphorus content in soils of V1, V2 and V3; A1, A2 and A3; I1, I2 and I3 was recorded to be 16.24, 11.09 and 15.15 kg ha^{-1} ; 30.53 30.79 and 24.91 kg ha^{-1} ; 22.00, 17.60 and 22.00 kg ha^{-1} respectively. This high available P content is attributed to the regular application of phosphatic fertilizers and the immobile nature of phosphate ions in soils, which must have resulted in accumulation of P in soils. Results were supported by Ravikumar and Somashekar (2014)^[7] similar results were reported by Dubliya, 2011 and Singh *et al.*, (2014)^[19].

3.2.3 Available K

The available K content in V1, V2 and V3 (Vertisols) were 328.68, 308.32 and $345.60 \text{ kg ha}^{-1}$, respectively. The K was recorded in I3, I1 and I2 (Inceptisols) with value of 389.76, 346.08 and $323.36 \text{ kg ha}^{-1}$ respectively. The available K was found to be 276.96, 352.80 and $358.08 \text{ kg ha}^{-1}$ in A2, A3 and A1, (Alfisols) respectively. The available K content in Vertisols were 328.68, 308.32 and $345.60 \text{ kg ha}^{-1}$ in V1, V2

and V3. The high value of K recorded in Inceptisols were 389.76, 346.08 and 323.36 kg ha⁻¹ in I3, I1 and I2, respectively. Among the Alfisols order the available K found 276.96, 352.80 and 358.08 kg ha⁻¹ in A2, A3 and A1, respectively. The high status of K in these soils may be due to predominance of K rich micaceous and feldspars minerals in parent material. Similar results reported by Ravikumar and Somashekar (2014)^[17].

3.3 Phosphorus adsorption isotherm of different soils

The P adsorption isotherms for the soils of Jabalpur is given in table 3.2. The value of equilibrium solution P concentrations were found minimum in Alfisols (0.03 to 8.95 µg mL⁻¹) and maximum in Inceptisols (0.09 to 10.95 µg mL⁻¹), but the adsorb P value was minimum in Inceptisols (19.01 to 290.41 µg mL⁻¹) and maximum were recorded in Alfisols (19.64 to 310.47 µg mL⁻¹). Similar Vertisols of JNKVV farm, where the value of equilibrium solution P concentrations were found in the range of (0.13 to 10.08 µg mL⁻¹), but the adsorb P values were (18.65 to 299.13 µg mL⁻¹). The soil order Inceptisols have lowering of P adsorption isotherms as compared to both the soil orders (Alfisols and Vertisols). Which indicating a marked decrease in P adsorbed and an increase in equilibrium solution P concentration. Minimum P adsorption occurred in the Inceptisol soil order. The P adsorption isotherms for the soils of Jabalpur is given in table 4.2. The value of equilibrium solution P concentrations were found in the range 0.03 to 8.95 mg µg mL⁻¹ in Vertisols, 0.09 to 10.95 µg mL⁻¹ in Inceptisols, and 0.13 to 10.08 µg mL⁻¹ in Alfisols, but the adsorb P value were found in the range 19.64 to 310.47 µg mL⁻¹ in Vertisols, 19.01 to 290.41 µg mL⁻¹ in Inceptisols and 18.65 to 299.13 µg mL⁻¹ in Alfisols. The graphical representation of equilibrium P concentration versus rate of P adsorbed on unit mass of soil colloid were used to calculate the maximum sorption capacity of the soils and the affinity of the soil to hold P. In all three soil orders, the equilibrium P solution and per unit P adsorption by soil colloids increased with increasing P addition (Dhillon *et al.*, 2004)^[3]. Similar results also reported by Rashmi *et al.*, (2016)^[16].

3.4 Phosphorus adsorption parameter

The P adsorption data of the soils under different soil orders options fitted well to the classical Langmuir equation, with highly significant R² values 0.993, 0.995 and 0.997 (Table 3.3) in the Alfisols, Inceptisols and Vertisols of JNKVV farm Jabalpur. The Langmuir P adsorption maxima (b) and bonding energy constant (k) derived from the Langmuir isotherms of P adsorption by soil varied widely among different soil orders. The value of adsorption maxima (b) was found to be 412.99, 467.54 and 484.01 mg P kg⁻¹ in I3, I2 and I1 (Inceptisols) soil order with the mean value of 452.98 mg P kg⁻¹ followed by 463.90, 480.10 and 497.36 mg P kg⁻¹ in A3, A2 and A3 (Alfisols) with the mean value of 480.89 mg P kg⁻¹ and maximum value of adsorption maxima (b) 526.01, 493.07 and 491.14 mg P kg⁻¹ in V3, V2 and V1 (Vertisol) soil order with the mean value of 504.26 mg P kg⁻¹. The bonding energy constant (k) was found to be 0.131, 0.143 and 0.141 L mg⁻¹ in Vertisols, Alfisols and Inceptisols soil order, respectively.

The Langmuir P adsorption maxima (b) and bonding energy constant (K) derived from the Langmuir isotherms of P adsorption by soil varied widely among different soil orders. The highest P sorption maxima followed the order Vertisol (504.26 mg kg⁻¹) > Alfisol (480.89 mg kg⁻¹) > Inceptisol

(452.98 mg kg⁻¹). The phosphate adsorption isotherm gave a good fit in case of Langmuir (r² = 0.993 to 0.997) equations as presented in table 4.3. Similar results were obtained by Quang *et al.* (1996)^[14] and Thakur *et al.* (2004)^[22]. High P sorption maxima in Vertisol was due to high clay content, whereas in Alfisol and Ultisol A1 and Fe sorbed more P. The high P fixing capacity is a major constraint in these soils because > 80% of P is unavailable to crop uptake due to sorption, precipitation or both (White, 1981)^[27]. The bonding energy constant (K) was found 0.131 L mg⁻¹ in Alfisols soil order and 0.140 L mg⁻¹ in Inceptisols soil order and the maximum bonding energy constant (K) was found 0.143 L mg⁻¹ in Vertisols. The binding energy of the soils for P adsorption decreased with increase in surface coverage and interaction with molecules already adsorbed tends to increase with increasing surface coverage, which is in agreement with (Quang, 1996)^[14].

3.5 Maximum P buffering capacity (MPBC)

The maximum P buffering capacity (MPBC) was found in range 60.07 to 70.89 L kg⁻¹. In different soil orders the highest value of MPBC was found (Table 3.3) to be 67.68, 68.33 and 70.89 L kg⁻¹ in A1, A2 and A3 (Alfisols) with the mean value 68.89 L kg⁻¹ and the lowest of MPBC value was found to be 60.07, 63.57 and 68.01 L kg⁻¹ in I2, I1 and I3 (Inceptisols) with the mean value was 63.72 L kg⁻¹. Whereas in Vertisols, the value of MPBC was found to be 64.31, 66.44 and 68.06 L kg⁻¹ in site V2, V1 and V3 with the mean value was 66.18 L kg⁻¹, respectively. The phosphate buffering capacity (PBC or MBC) was found to be highest in Alfisols (68.89 L kg⁻¹), Vertisols (66.18 L kg⁻¹) and Inceptisols (63.72 L kg⁻¹). The soils with high MBC namely Alfisols and Vertisols have high adsorption capacity and would maintain low P supply in soil solution for a longer period as compared to least buffered soils which can supply P to soil solution. On the other hand, soils with low buffering capacity will have more P in soil solution and will enhance P mobility in such soils.

3.6 Standard Phosphorus Requirement (SPR)

Amount of P adsorbed at 0.2 mg L⁻¹ equilibrium solution P concentration is generally accepted as standard P requirement (SPR) of a soil for optimum crop yield. In the present study, the SPR of soil showed variation depending upon the different order of soils (Table 3.3). The value of SPR ranged from 3.31 to 9.61 mg kg⁻¹. In different soil orders, the highest value of SPR was found to be 7.22, 7.28 and 9.61 mg kg⁻¹ in I2, I1 and I3 (mean 8.04 mg kg⁻¹) followed by Vertisols was 6.76, 7.78 and 7.80 mg kg⁻¹ in V3, V1 and V2 (mean 7.45 mg kg⁻¹) and the lowest SPR was found in Alfisols was 3.31, 3.38 and 4.68 mg kg⁻¹ in A2, A1 and A3 (mean 3.79 mg kg⁻¹), respectively. Amount of P adsorbed at 0.2 mg L⁻¹ equilibrium solution P concentration is generally accepted as standard P requirement (SPR) of a soil for optimum crop yield. In the present study, the SPR of soil showed variation depending upon the different order of soils (Table 4.3). The amount of standard phosphorus requirement (SPR) for, Inceptisols, Vertisols and Alfisols was 8.04, 7.45 and 3.79 mg kg⁻¹ respectively in 0.2 mg P L⁻¹ equilibrium soil solution concentration. The higher values of SPR in case of Inceptisols and Vertisols indicate the need for application of P fertilizers to maintain optimum crop production. From environmental point of view P leaching can occur at early stage from coarse textured Inceptisols compared to Vertisols and Alfisols Rashmi *et al.*, (2016)^[16].

3.7 Relationship of physico-chemical properties with phosphorus adsorption parameters in soil

Relationship of physico-chemical properties with phosphorus fractions in Vertisols soil order are presented in (Table 3.4) revealed that the pH had positive correlation with Adsorption maxima (b) ($r=0.993$) and Maximum P buffering Capacity ($r=0.715$), but negative relationship with Bonding energy (k) ($r=-0.752$) and Standard P requirement (SPR) ($r=-0.982$). The EC had negative relationship with b ($r=-0.769$), but positive relationship with k ($r=0.989$). The OC had negative relationship with Maximum P buffering Capacity ($r=-0.928$). The clay percent had negatively correlation with Maximum P buffering Capacity ($r=-0.773$). The CEC had significant negative correlation with Maximum P buffering Capacity ($r=-0.999^{**}$), but positive relationship with SPR ($r=0.812$), respectively.

In Alfisols soil order the correlation of physico-chemical

properties with phosphorus fractions are presented in (Table 3.4) revealed that the pH had negative correlation with b ($r=-0.975$), but positively relationship with k ($r=0.916$) and Maximum P buffering Capacity ($r=0.839$). The clay percent had negatively correlation with Maximum P buffering Capacity ($r=-0.865$) and SPR ($r=-0.959$). The CEC had negative correlation with b ($r=-0.762$), respectively.

Correlation of physico-chemical properties with phosphorus fractions in Inceptisols soil order are revealed that the EC had positive relationship with b ($r=0.734$), but negative relationship with k ($r=-0.900$), Maximum P buffering Capacity ($r=-0.998$) and SPR ($r=-0.877$). The OC had negative relationship with b ($r=-0.735$). The clay percent had negatively correlation with k ($r=-0.993$), Maximum P buffering Capacity ($r=-0.965$) and SPR ($r=-0.986$), but positive relationship with b ($r=0.916$). The CaCO_3 had significant negative correlation with b ($r=-0.856$), respectively.

Table 3.2: Phosphorus adsorption isotherm of different soils of JNKVV Farm, Jabalpur

P $\mu\text{g mL}^{-1}$	Vertisols		Alfisols		Inceptisols	
	Eq. C. ($\mu\text{g mL}^{-1}$)	Ads. ($\mu\text{g g}^{-1}$)	Eq. C. ($\mu\text{g mL}^{-1}$)	Ads. ($\mu\text{g g}^{-1}$)	Eq. C. ($\mu\text{g mL}^{-1}$)	Ads. ($\mu\text{g g}^{-1}$)
	C	x/m	C	x/m	C	x/m
2	0.135	18.651	0.036	19.644	0.099	19.013
4	0.554	34.461	0.436	35.635	0.498	35.025
8	1.869	61.308	2.113	58.873	2.180	58.204
16	3.211	127.891	3.766	122.341	3.091	129.091
24	3.302	206.983	4.074	199.263	4.568	194.325
32	7.335	246.646	6.473	255.269	7.817	241.832
40	10.087	299.132	8.953	310.473	10.953	290.471

Table 3.3: Phosphorus adsorption parameters in surface soils of JNKVV Farms, Jabalpur

Site	Adsorption maxima (b) (mg P kg^{-1})	Bonding energy (K) (L mg^{-1})	Maximum P buffering Capacity (L kg^{-1})	Amount of p sorbed (mg kg^{-1}) at 0.2 mg P L^{-1} of solution (SPR)	R ²
(V1)	491.14	0.135	66.44	7.78	0.997
(V2)	493.07	0.130	64.31	7.80	0.997
(V3)	526.01	0.129	68.06	6.76	0.997
Mean	504.26	0.131	66.18	7.45	0.997
(A1)	497.36	0.136	67.68	3.38	0.993
(A2)	480.10	0.142	68.33	3.31	0.992
(A3)	463.90	0.153	70.89	4.68	0.993
Mean	480.89	0.143	68.89	3.79	0.993
(I1)	484.01	0.131	63.57	7.28	0.996
(I2)	467.54	0.128	60.07	7.22	0.996
(I3)	412.99	0.165	68.01	9.61	0.993
Mean	452.98	0.141	63.72	8.04	0.995

Table 4.4: Relationship of physico-chemical properties with phosphorus adsorption parameters in soil

Soil orders		Adsorption maxima (b)	Bonding energy (K)	Maximum P buffering Capacity	Standard P requirement (SPR)
Vertisols	pH	0.993	-0.752	0.715	-0.982
	EC	-0.769	0.989	-0.225	0.726
	OC	-0.510	-0.292	-0.928	0.569
	Clay	-0.230	-0.573	-0.773	0.293
	CEC	-0.772	0.04	-0.999*	0.812
	CaCO_3	-0.066	-0.700	-0.657	0.131
Alfisols	pH	-0.975	0.916	0.839	0.687
	EC	0.258	-0.074	0.088	0.321
	OC	0.158	0.028	0.189	0.416
	Clay	0.641	-0.772	-0.865	-0.959
	CEC	-0.762	0.629	0.495	0.276
	CaCO_3	0.611	-0.453	-0.303	-0.070
Inceptisols	pH	0.548	-0.279	0.099	-0.328
	EC	0.734	-0.900	-0.998*	-0.877
	OC	-0.735	0.504	0.146	0.548
	Clay	0.916	-0.993	-0.965	-0.986
	CEC	0.000	-0.291	-0.627	-0.242
	CaCO_3	-0.856	0.668	0.342	0.705

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